Engineered Resilient Systems
A DoD Science and Technology Priority Area

Overview Presentation
June 2012

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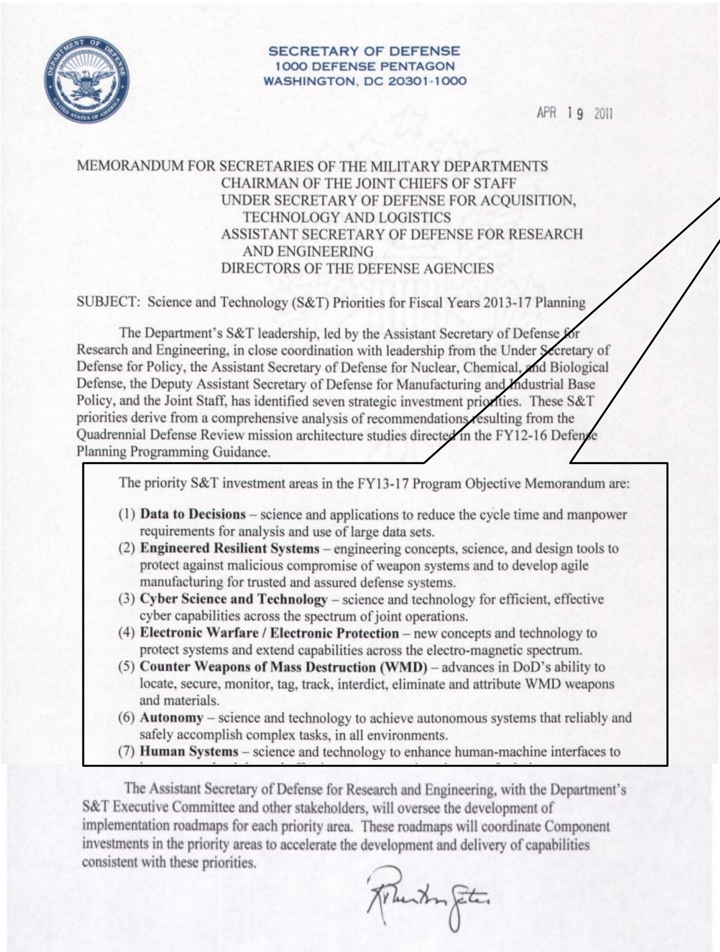
Secretary of Defense Guidance on Science & Technology (S&T) Priorities FY13-17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MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY AND LOGISTICS
ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING
DIRECTORS OF THE DEFENSE AGENCIES

SUBJECT: Science and Technology (S&T) Priorities for Fiscal Years 2013-17 Planning

The Department's S&T leadership, led by the Assistant Secretary of Defense for Research and Engineering, in close coordination with leadership from the Under Secretary of Defense for Policy, the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense, the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy, and the Joint Staff, has identified seven strategic investment priorities. These S&T priorities derive from a comprehensive analysis of recommendations resulting from the Quadrennial Defense Review mission architecture studies directed in the FY12-16 Defense Planning Programming Guidance.

The priority S&T investment areas in the FY13-17 Program Objective Memorandum are:

(1) **Data to Decisions** – science and applications to reduce the cycle time and manpower requirements for analysis and use of large data sets.
(2) **Engineered Resilient Systems** – engineering concepts, science, and design tools to protect against malicious compromise of weapon systems and to develop agile manufacturing for trusted and assured defense systems.
(3) **Cyber Science and Technology** – science and technology for efficient, effective cyber capabilities across the spectrum of joint operations.
(4) **Electronic Warfare / Electronic Protection** – new concepts and technology to protect systems and extend capabilities across the electro-magnetic spectrum.
(5) **Counter Weapons of Mass Destruction (WMD)** – advances in DoD's ability to locate, secure, monitor, tag, track, interdict, eliminate and attribute WMD weapons and materials.
(6) **Autonomy** – science and technology to achieve autonomous systems that reliably and safely accomplish complex tasks, in all environments.
(7) **Human Systems** – science and technology to enhance human-machine interfaces to

The Assistant Secretary of Defense for Research and Engineering, with the Department's S&T Executive Committee and other stakeholders, will oversee the development of implementation roadmaps for each priority area. These roadmaps will coordinate Component investments in the priority areas to accelerate the development and delivery of capabilities consistent with these priorities.

Priority S&T Investment Areas:

1. Data to Decisions
2. Engineered Resilient Systems
3. Cyber Science and Technology
4. Electronic Warfare / Electronic Protection
5. Counter Weapons of Mass Destruction
6. Autonomy
7. Human Systems

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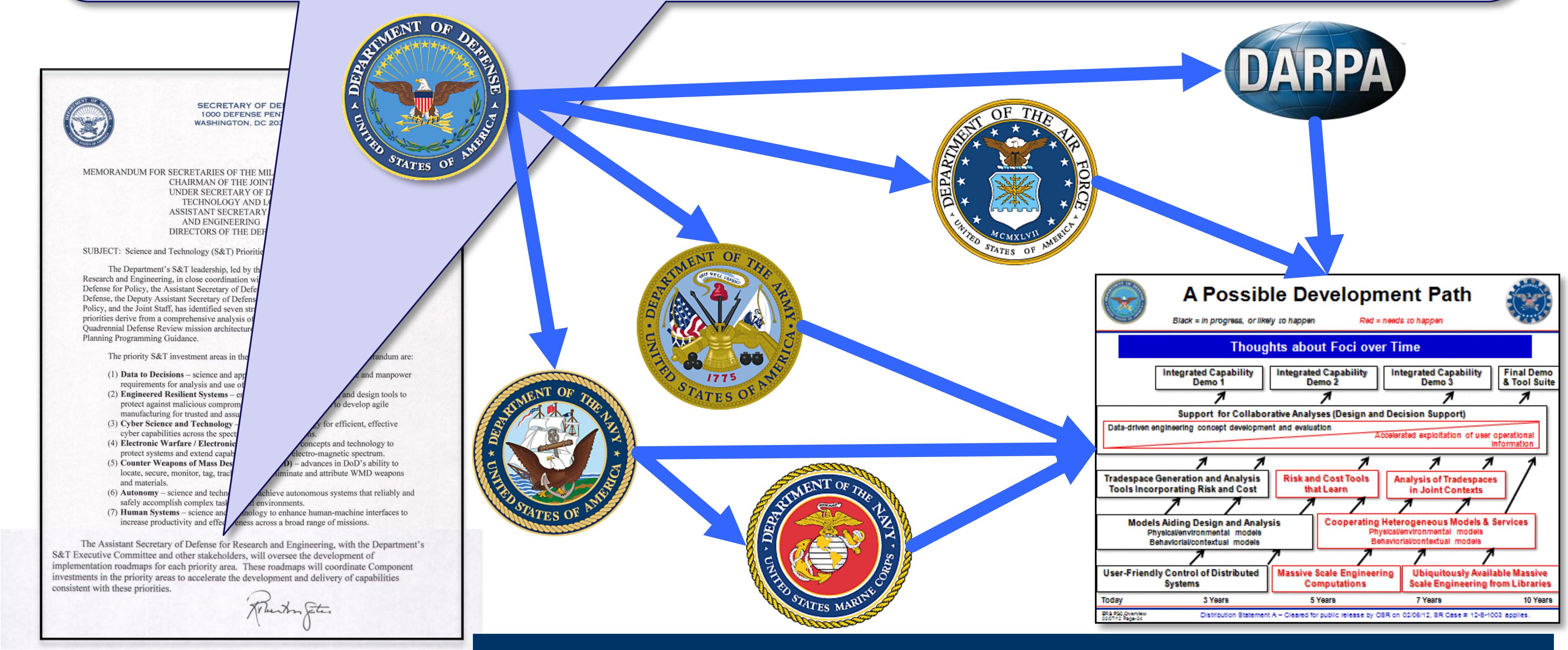
Engineered Resilient Systems: A DoD-wide Activity

The Assistant Secretary of Defense for Research and Engineering, with the Department's S&T Executive Committee and other stakeholders, will oversee the development of implementation roadmaps for each priority area. These roadmaps will coordinate Component investments in the priority areas...



Working Toward A DoD-Wide Roadmap

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Resilient Systems, Defined

A resilient system is trusted and effective out of the box in a wide range of contexts, easily adapted to many others through reconfiguration or replacement, with graceful and detectable degradation of function.

Research in Engineered Resilient Systems focuses on agile and cost-effective design, development, testing, manufacturing, and fielding of trusted, assured, easily- modified systems

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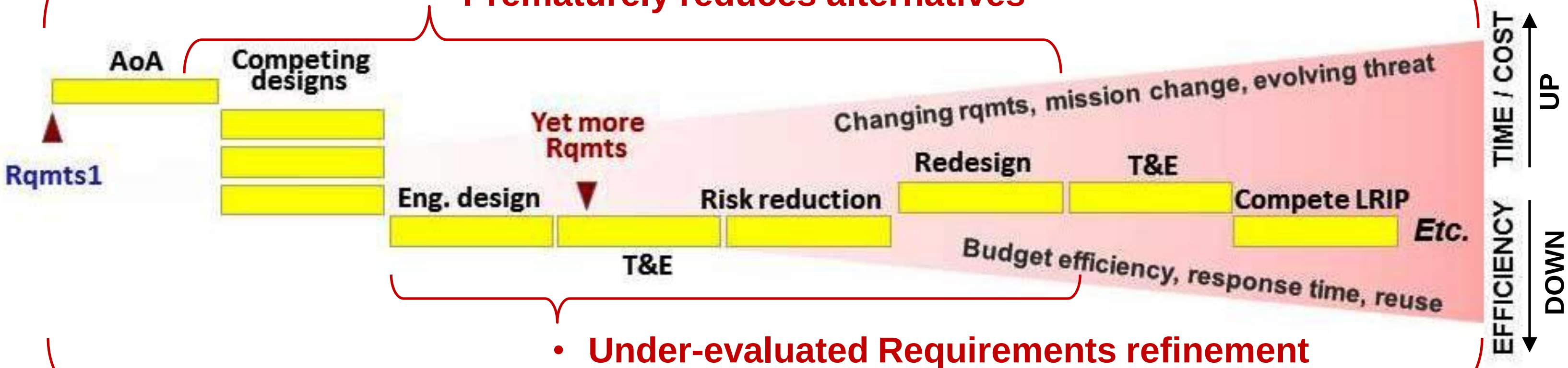
Conventional Engineering Practice

50 years of process reforms haven't controlled time, cost and performance

- **Sequential and slow**
- **Information lost at every step**
- **Prematurely reduces alternatives**



- **Under-evaluated Requirements refinement**
- **Decisions made with incomplete information**

Engineering practice must meet new challenges:

- **Pace of technology development**
- **Uncertain sociopolitical futures**
- **Global availability of technology to potential competitors**

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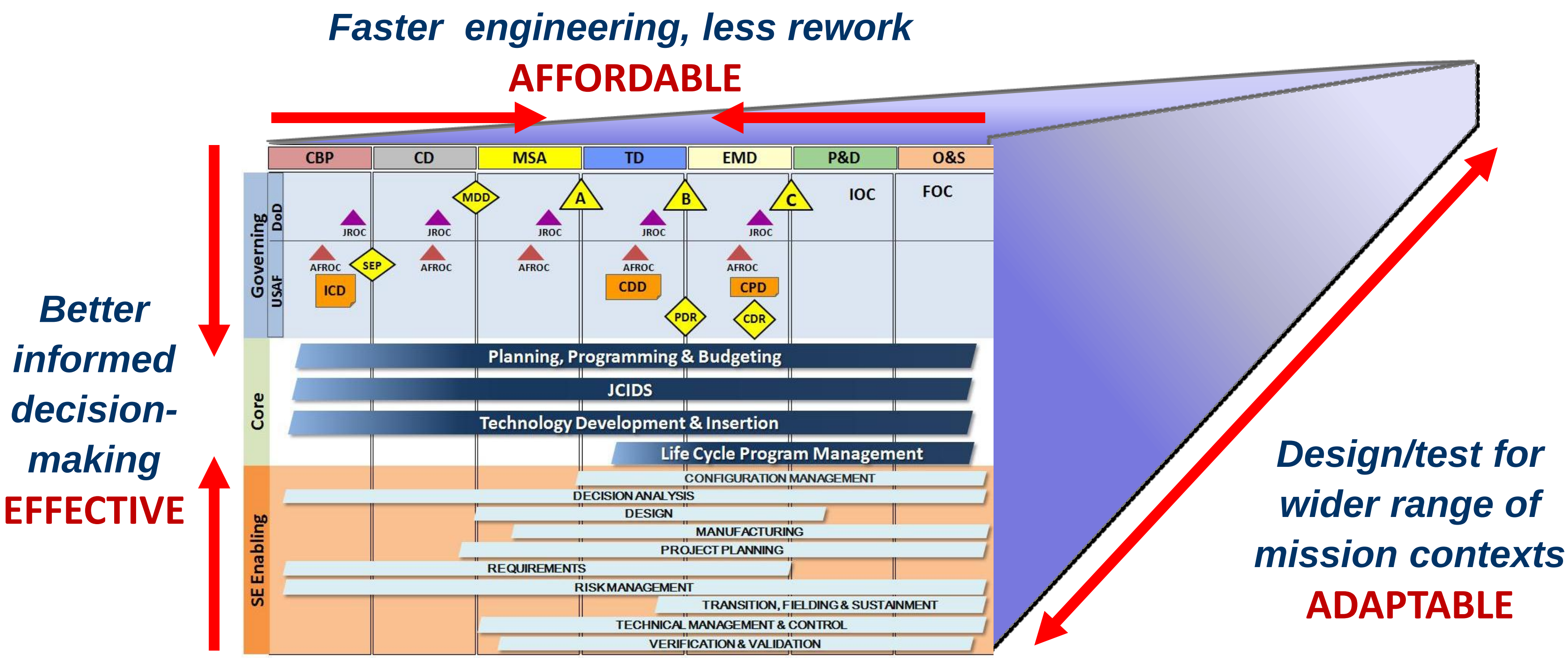
Transforming Engineering of Complex Systems

Engineering for resilience: *robust* systems with *broad utility*

- ***In a wide range of joint operations***
- ***Across many potential alternative futures***



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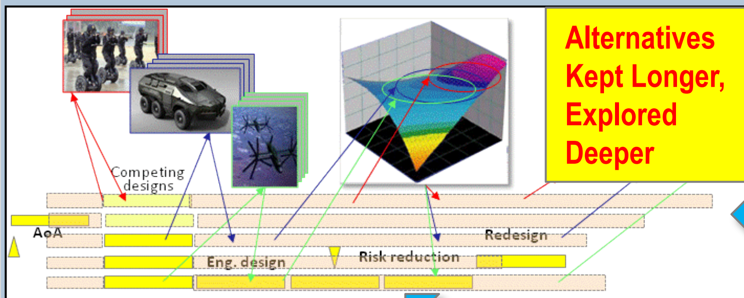
Engineered Resilient Systems
Transformational Engineering Practices

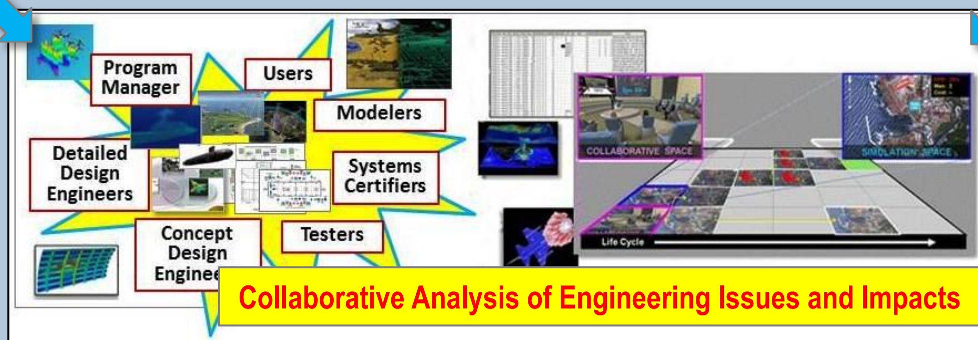
Increased computational power and availability allow more flexibility in data exploitation and application of services



New tools help engineers & users:
- *Understand interactions*
- *Identify implications*
- *Manage consequences*

Effective
- *Better informed*

Affordable
- *Faster engineering*



Adaptable
- *Wider range of mission contexts*

ERS envisions an ecosystem in which a wide range of stakeholders continually cross-feed multiple types of data that inform each other's activities

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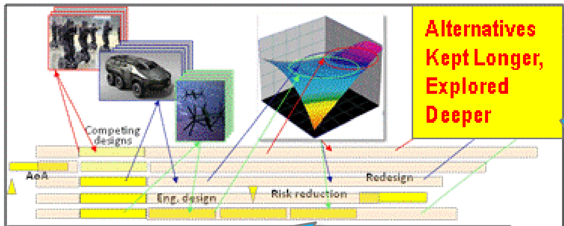
Key Technical Thrust Areas

Systems Representation and Modeling

– Physical, logical structure, behavior, interactions, interoperability…



Characterizing Changing Operational Contexts

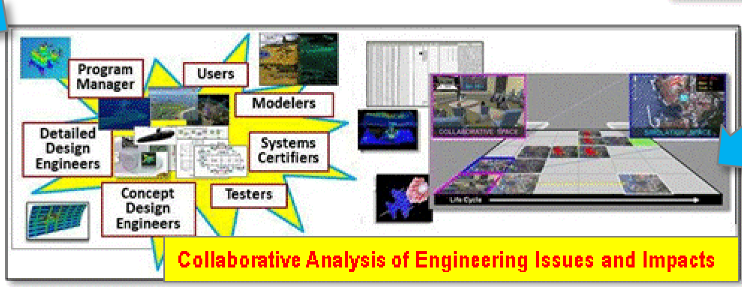
– Deep understanding of warfighter needs, impacts of alternative designs

Cross-Domain Coupling

– Model interchange & composition across scales, disciplines

Data-driven Tradespace Exploration and Analysis

– Multi-dimensional generation/evaluation of alternative designs



Collaborative Design and Decision Support

– Enabling well-informed, low-overhead discussion, analysis, and assessment among engineers and decision-makers

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A Possible Development Path

Black = in progress, or likely to happen *Red = needs to happen*

Thoughts about Foci over Time

Integrated Capability Demo 1

Integrated Capability Demo 2

Integrated Capability Demo 3

Final Demo & Tool Suite

Support for Collaborative Analyses (Design and Decision Support)

Data-driven engineering concept development and evaluation

Accelerated exploitation of user operational information

Tradespace Generation and Analysis Tools Incorporating Risk and Cost

Risk and Cost Tools that Learn

Analysis of Tradespaces in Joint Contexts

Models Aiding Design and Analysis
Physical/environmental models
Behaviorial/contextual models

Cooperating Heterogeneous Models & Services
Physical/environmental models
Behaviorial/contextual models

User-Friendly Control of Distributed Systems

Massive Scale Engineering Computations

Ubiquitously Available Massive Scale Engineering from Libraries

Today | 3 Years | 5 Years | 7 Years | 10 Years

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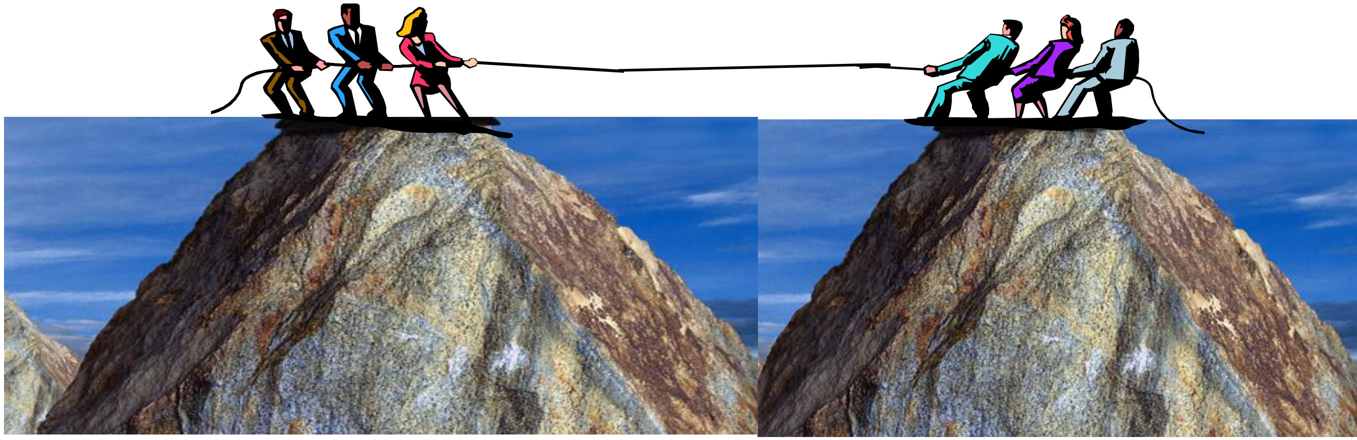
Who Owns the Tools?

No Single Winning Answer



Pull too hard and everyone loses

Looking for a Win-Win

- **Tools for Government**
  - **Better understanding and specifier of needs**
  - **Better evaluator of offerings**
- **Tools for Systems Providers**
  - **Risk mitigation through better understanding of customer**
  - **Ability to pre-qualify offerings, present meaningful opportunities**
- **Tool Vendors: New Products to Sell Both**

Key Connectors are Data Exchange Protocols and Architectures

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Building on Proven Concepts

Leverage and build upon promising technologies to transform engineering capabilities

Engineered Resilient Systems

ERS

Modeling Technologies
Physics-based Models for Engineering and Training

Network-Centric Operations
Command & Control

Risk Management
Financial & Business Analysis Community

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Envisioned End State

Improved Engineering and Design Capabilities

- More environmental and mission context
- More alternatives developed, evaluated and maintained
- Better trades: managing interactions, choices, consequences

Improved Systems

- Highly effective: better performance, greater mission effectiveness
- Easier to adapt, reconfigure or replace
- Confidence in graceful degradation of function

Improved Engineering Processes

- Fewer rework cycles
- Faster cycle completion
- Better managed requirements shifts

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SUPPLEMENTAL MATERIAL

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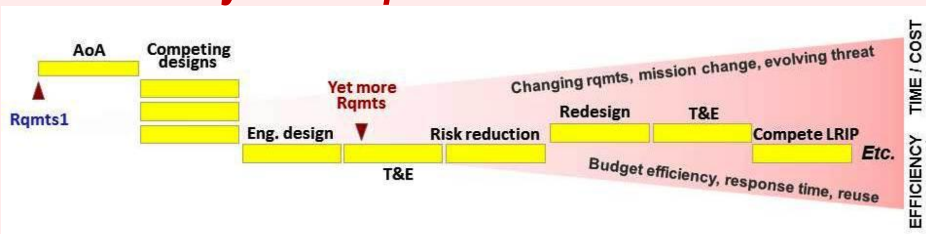
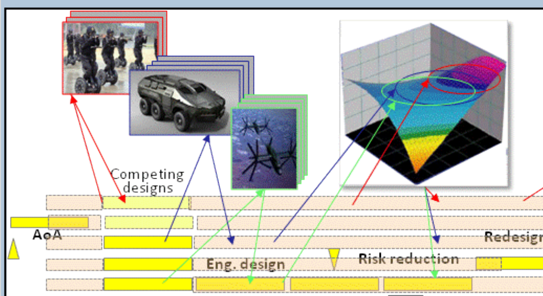
Engineered Resilient Systems (ERS)

More effective, affordable, adaptable

50 years of process reforms haven't controlled time, cost and performance



- Prematurely reduces alternatives
- Decisions made with incomplete information
- Sequential, slow
- Information lost at every step
- Ad hoc requirements refinement



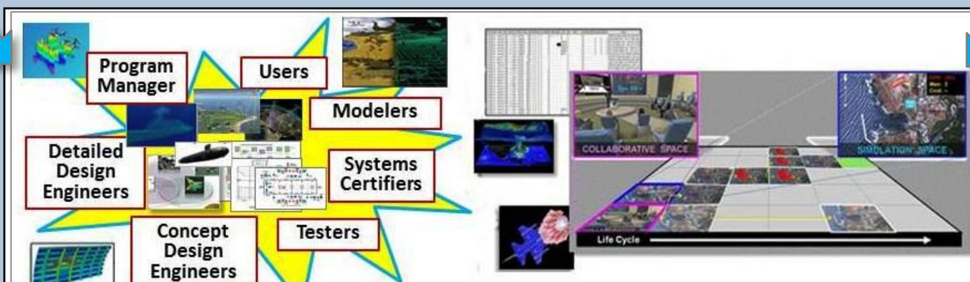
Alternatives Kept Longer, Explored Deeper

Refinement in Context of Operational Missions

Effective
- ***Better informed***

Affordable
- ***Faster engineering***

Adaptable
- ***Wider range of mission contexts***



Collaborative Analysis of Engineering Issues and Impacts

ERS envisions an ecosystem in which a wide range of stakeholders continually cross-feed multiple types of data that inform each other's activities

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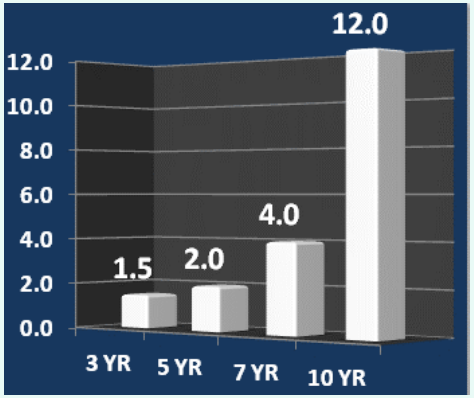
What Constitutes Success?

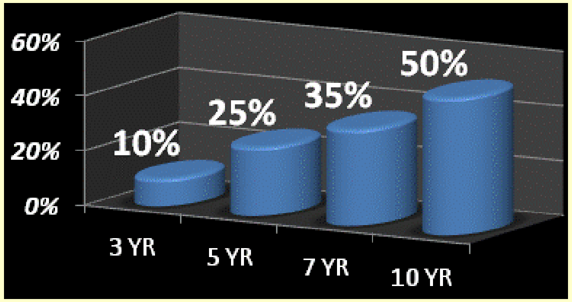


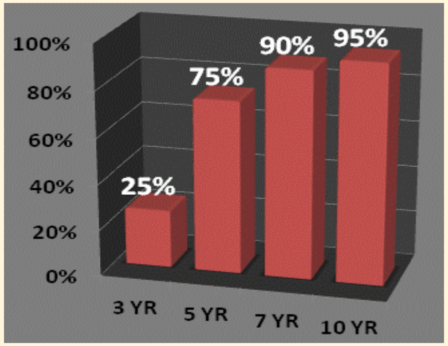
Faster, more efficient engineering iterations

- Virtual design – integrating 3D geometry, electronics, software
- Find problems early:
  - Shorter risk reduction phases with prototypes
  - Fewer, easier redesigns
  - Accelerated design/test/build cycles
- ***Target: 12x speed-up in development time***

Adaptable (and thus robust) designs

- Diverse system models, easily accessed and modified
- Potential for modular design, re-use, replacement, interoperability
- Continuous analysis of performance, vulnerabilities, trust
- ***Target: 50% of system is modifiable to new mission***





Decisions informed both ways (engineering by mission needs, missions by engineering opportunities/risks)

- More options considered deeply, broader trade space analysis
- Interaction and iterative design among collaborative groups
- Ability to simulate & experiment in synthetic operational environments
- ***Target: 95% of system informed by trades across ConOps/env.***

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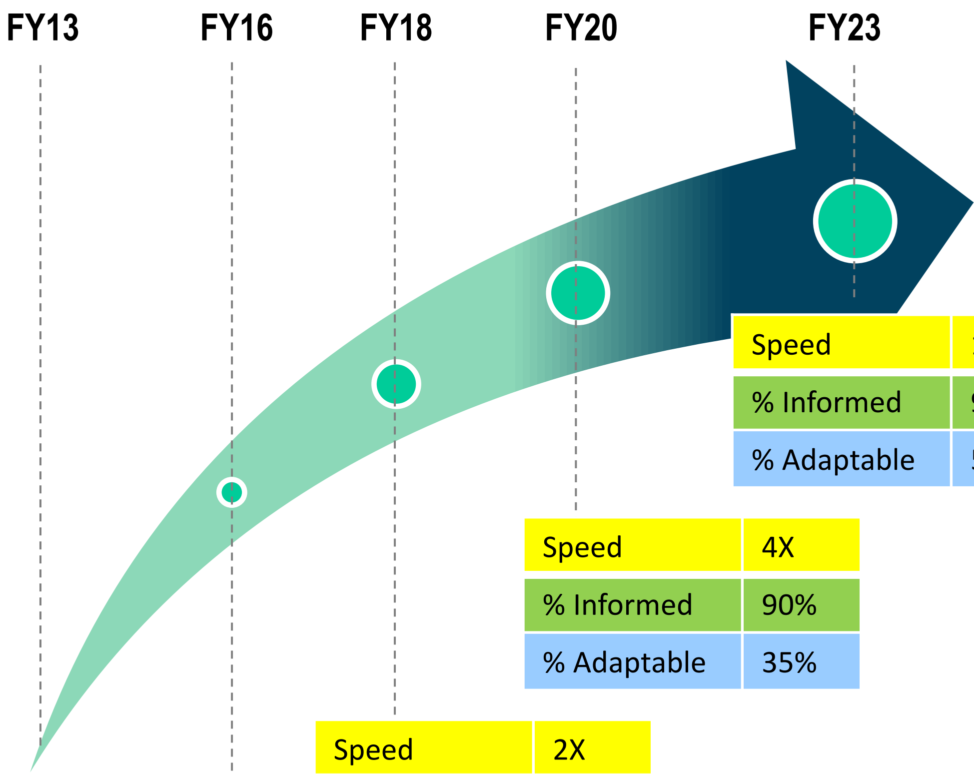
Potential High-level Goals and Metrics over 10 Years



FY16

Speed	1.5X
% Informed	25%
% Adaptable	10%

FY18

Speed	2X
% Informed	75%
% Adaptable	25%

FY20

Speed	4X
% Informed	90%
% Adaptable	35%

FY23

Speed	12X
% Informed	95%
% Adaptable	50%

ERS

- **How Fast?**
  - Developmental response time improvement (relative to baseline)
- **How Informed?**
  - Percent of system informed by models and trades within operational environment
- **How Adaptable?**
  - Percent reduction in cost and effort required to adapt system to support new mission

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Potential Detailed Goals and Metrics

	FY13	3 Yrs / FY16	5 Yrs / FY18	7 Yrs / FY20	10 Yrs / FY23
System Representation & Modeling, plus Cross-Domain Coupling	*Breadth*	25% of whole sys/subsys	75% of whole sys/subsys	90% of whole sys/subsys	95% of whole sys/subsys
	*Fidelity**	±20% error limit	±10% error limit	±5% error limit	±2% error limit
	Degree of Integration	Electronics and CAD (swap circuit board)	Cross-scaling (swap micro-processors)	Software and micro elec (change oper system)	Ability to swap major subsys, remodel without redesign
	** = Predict behaviors accurately*				
Characterizing the Changing Operational Context	*Breadth*	25%** of whole sys/subsys	75% of whole sys/subsys	90% of whole sys/subsys	95% of whole sys/subsys
	*Fidelity**	±20% error limit	±10% error limit	±5% error limit	±2% error limit
	Degree of Integration	Single model sys embedded in simple realistic env	Single model sys embedded in complex realistic env	Mult modeled systems integrated in a simple, realistic env	Mult modeled systems interacting in a complex realistic system
	** = % of sys in realistic, simulated environment*				
Data-driven Tradespace Exploration &Analysis		100 Trades SOA Basic algorithms Add 2 dimensions (such as affordability and reliability)	1000 Trades Cloud data Application prototype Add 1 dimension	10,000 Trades Implementation Heuristics Add 1 dimension	100,000 Trades Full service Tradespace algorithms that "think" Add 2 dimensions
Collaborative Design/ Decision Support		2 domains of expertise collaborate on a design w/o speed degradation	4 domains of expertise collaborate on a design w/o speed degradation	8 domains of expertise collaborate on a design w/o speed degradation	16 domains of expertise collaborate on a design w/o speed degradation
ERS Capability Exercise (OSD)		Speed 1.5X % Informed 25% % Adaptable 10%	Speed 2X % Informed 75% % Adaptable 25%	Speed 4X % Informed 90% % Adaptable 35%	Speed 12X % Informed 95% % Adaptable 50%

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System Representation and Modeling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Capturing • ***Physical and logical structures*** • ***Behavior*** • ***Interaction with the environment and other systems***	**Model 95% of a complex weapons system**	• Combining live and virtual worlds • Bi-directional linking of physics-based & statistical models • Key multidisciplinary, multiscale models • Automated and semi-automated acquisition techniques • Techniques for adaptable models

We need to create and manage many classes (*executable, depictional, statistical...*) and many types (*device and environmental physics, comms, sensors, effectors, software, systems ...*) of models

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Characterizing Changing Operational Environments: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Deeper understanding of warfighter needs ***Directly gathering operational data*** ***Understanding operational impacts of alternatives***	**Military Effectiveness Breadth Assessment Capability**	• Learning from live and virtual operational systems • Synthetic environments for experimentation and learning • Creating operational context models (missions, environments, threats, tactics, and ConOps) • Generating meaningful tests and use cases from operational data • Synthesis & application of models

"Ensuring adaptability and effectiveness requires evaluating and storing results *from many, many scenarios* (including those presently considered unlikely) *for consideration earlier* in the acquisition process."

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Cross-Domain Coupling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps

Better interchange between incommensurate models
 	
Resolving temporal, multi-scale, multi-physics issues
	Weapons system modeled fully across domains	• Dynamic modeling/analysis workflow
		• Consistency across hybrid models
		• Automatically generated surrogates
		• Semantic mappings and repairs
		• Program interface extensions that:
		  • Automate parameterization and boundary conditions
		  • Coordinate cross-phenomena simulations
		  • Tie to decision support
		  • Couple to virtual worlds

Making the wide range of model classes and types work together effectively requires new computing techniques (not just standards)

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Tradespace Analysis: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Efficiently generating and evaluating alternative designs ***Evaluating options in multi-dimensional tradespaces***	**Trade analyses over *very large* condition sets**	• Guided automated searches, selective search algorithms • Ubiquitous computing for generating/evaluating options • Identifying high-impact variables and likely interactions • New sensitivity localization algorithms • Algorithms for measuring adaptability • Risk-based cost-benefit analysis tools, presentations • Integrating reliability and cost into acquisition decisions • Cost-and time-sensitive uncertainty management via experimental design and activity planning

Exploring more options and keeping them open longer, by managing complexity and leveraging greater computational testing capabilities

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Collaborative Design & Decision Support: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Well-informed, low-overhead collaborative decision making	**Computational / physical models bridged by 3D printing** ***Data-driven*** **trade decisions executed and recorded**	• Usable multi-dimensional tradespaces • Rationale capture • Aids for prioritizing tradeoffs, explaining decisions • Accessible systems engineering, acquisition, physics and behavioral models • Access controls • Information push-pull without flooding

ERS requires the transparency for many stakeholders to be able to understand and contribute, with low overhead for participating

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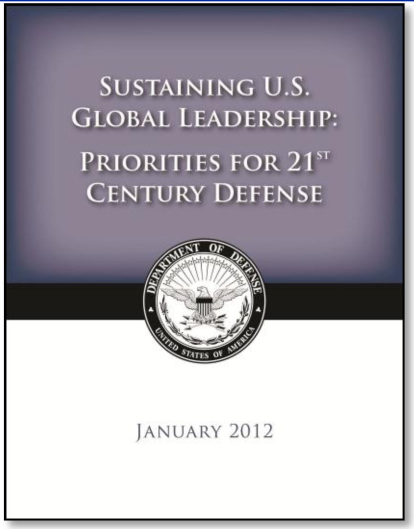
ERS: *Foundational* for Defense Systems across All Mission Areas


SUSTAINING U.S. GLOBAL LEADERSHIP: PRIORITIES FOR 21ST CENTURY DEFENSE

JANUARY 2012

Seven Strategic Principles to Ensure Success, including:

- ***Offer versatility***
- ***Enable course changes***
- ***Reduce costs***
- ***Develop new capabilities leveraging network warfare***

Ten DoD Strategic Missions

Overwhelming majority require affordable, adaptable & effective systems and Concepts of Operation:

Missions Needing Engineering

Strategic Principles to Ensure Success

Engineered Resilient Systems:
Engineering Technology and Tools to Rapidly Develop, Deliver, and Adapt Affordable, Versatile Systems and Concepts of Operation

Target Outcomes

- 50% reduction in cost and effort to adapt to new mission
- 12X Speed up in time to initial operating capability
- 95% of system informed by models and operational trades

Key ERS Contributing Concepts

- **Co-evolution of systems and missions via information sharing and decision aids**
- **Option-preserving tradespace exploration**
  - **Analyzed/evaluated wrt lifecycle issues**
  - **Informing requirements refinement**
- **Accelerated design and testing via rapidly composable modeling & analysis tools, risk-sensitive engineering planning aids**

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